PATENT APPLICATION

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TITLE OF INVENTION
ION BEAM DEFINITION OF MAGNETORESISTIVE FIELD SENSORS

INVENTORS
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FIELD OF THE INVENTION
This invention relates generally to forming magnetoresistive
15   field sensors. More particularly, this invention relates to
magnetic recording systems.

BACKGROUND ART
Sensors for detecting and measuring magnetic fields find many
20   scientific and industrial applications.   For example, a
magnetic recording head typically includes a sensing element
that senses a magnetic flux emanating from a recording medium.
The magnetic field changes some physical property of the
sensing element in a manner that depends on the magnitude and
25   direction of the magnetic field.   A sensing element that
changes its electrical resistivity in response to a magnetic
field is usually referred to as a magnetoresistive field
sensor.   Prior magnetoresistive field sensors typically
include one or more ferromagnetic elements whose resistivity
30   changes in response to magnetic flux. Prior magnetoresistive
field sensors include anisotropic magnetoresistive (AMR)
sensors and giant magnetoresistive (GMR) sensors, in which a
sense current flows along, or perpendicular to, planes of the
ferromagnetic elements. Prior magnetoresistive field sensors

also include magnetoresistive tunnel junction (MTJ) sensors, in which a sense current flows perpendicular to the planes of the ferromagnetic elements through a dielectric barrier. Resistance of a magnetoresistive field sensor varies as the square of the cosine of the angle between the magnetization in the sensor and the direction of sense current. Recorded data can be read from a magnetic medium because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization in the sensor, which in turn causes a change in resistance in the sensor and a corresponding change in the sense current or voltage.

Increasing areal density of magnetic storage media requires that the magnetic recording and reading heads be able to operate at ever-decreasing track widths (TW). Both the write element and the magnetic readback sensor of the recording head must be made smaller in order to achieve narrower data tracks. The width of the recorded track is determined by, among other parameters, the width of the write pole of the write head and the flying height of the write head. The size and geometry of the shields and leads also play a role in determining achievable track width for a given recording head design.

In order to take advantage of the narrower write track width, it is imperative that the read track width of the readback element or read head be reduced as well. At present, magnetoresistive (MR) heads are typically made by photolithographically defining the sensor element from a continuous multilayer thin film. The sensor, which is frequently rectangular in shape, is often defined in two steps, one photolithographic step to define the TW dimension, and one lapping step to define the so-called "stripe height" (SH) dimension. Unfortunately, due to practical limitations of the lithographic method, such as the diffraction limit of

light, it is not easy in a manufacturing environment to produce read heads much narrower than about 200nm. Meanwhile, MR head technology is already pushing present photolithographic techniques to their limits and these present

5   methods will not be able to accommodate future generations of MR heads. For example, in current commercial products, the sensor TW, which is defined by optical lithography and ion beam milling, is typically less than 1μm. It is envisaged that in order to make heads suitable for recording densities

10   of 100Gbits/in^2, the sensor TW will need to be around 0.13μm, but current lithography is wavelength-limited to around 0.2μm.

An associated problem that arises from the current processing method is poor shape definition, which leads to a "tail" on

15   each side of the sensor. The tails are a result of the ion beam milling process commonly used to define TW. The milling is performed with the ion beam at an angle to the wafer in an effort to minimize the redeposition of magnetic material at the mask edges, which would have a deleterious effect on the

20   sensor performance. However, ion milling at an angle creates a shadow near the mask edges, within which the milling is less efficient, resulting in tails on the sensor structure. The beam divergence from the ion mill also contributes to the tails. The presence of the tails degrades the magnetic

25   performance of the sensor. Further, the tails may vary in dimension and form across the wafer, resulting in sensor-to-sensor variation in performance. Fig. 1 illustrates a cross-sectional schematic diagram of a contiguous junction design MR sensor **100**. MR sensor **100** includes a first magnetic shield

30   **102**, and a first insulating gap **104** disposed on the shield **102**. The sensing element **106** including tails **108** is disposed on the gap **104**. Following the milling process, the top of the multilayer sensing element **106** will have a width determined by the resist mask used. However, the all-important sense layer,

which is located further down in the multilayer stack that forms sensing element **106**, will inevitably have a larger and possibly not well-controlled width. This problem is predicted to become increasingly important as the TW decreases and the tails become proportionally larger relative to the sensor dimensions.

Once the sensing element **106** is formed using optical lithography and milling, it is usual to deposit a ferromagnetic layer, called "hard bias" layer **110**, with substantial magnetic coercivity (Hc) on each side of the sensing element **106** to stabilize the magnetization at each side of the sensing element, thereby improving sensor performance. However, the tails **108** on each side of the sensing element **106** make deposition of a uniform hard bias layer **110** difficult, and the hard bias layer **110** becomes very thin near the top surface of the sensing element **106** and/or does not closely abut the sensing element **106**, leading to poor sensor performance.

MR sensor **100** further includes leads **112** adjacent to hard bias layers **110** to conduct the sense current to the sensing element **106** when reading data stored on a magnetic recording medium, a second gap **114** and a second shield **115** to protect the sensing element **106**.

A U.S. patent application entitled "Track Width Control of Readback Element" field 6/30/99, to Patrick C. Arnett et al. discloses a method for reducing the track width of readback elements by implantation of ions. The ion implantation reduces the magnetoresistance of the selected portions of the readback elements. The ion implantation of Arnett et al. is performed by a focused ion beam (FIB) technique. However, FIB processing is slow, since each element is processed in series,

which is not desirable for mass manufacture of magnetic sensors. Furthermore, electrostatic discharge (ESD) damage can occur during the application of the FIB to the sensor element, and therefore grounding during processing and low ion currents will be required to minimize this risk. In addition, the FIB processing of Arnett et al. is performed from the air-bearing surface (ABS). The layers that make up the sensor typically run perpendicular to the ABS and have stripe heights about an order of magnitude or more greater than the sensor film thickness. Consequently the ions must penetrate to a greater depth than the sensor film thickness in order to define the magnetically sensitive "tip portion". A large depth requirement demands high ion energies (incidentally, well beyond the range of standard FIB machines). The increased ion energy will cause an increase in the lateral straggle of the ions in the sensor material, and will widen the transition region between the tip portion and the neighboring "magnetically deactivated" region, presumably degrading the performance of the sensor. In order to conduct "implantation" amounting to a typical few atomic percent of the critical layers, this technique requires extremely large ion doses with long processing times, resulting in problems with heat dissipation and surface sputtering. Furthermore, this technique teaches an implantation based on a geometry which is quite unlike that used in recording heads or other MR sensors.

An article entitled "Patterning Ferromagnetism in $Ni_{80}Fe_{20}$ Films via 30keV Ga^+ Ion Irradiation" submitted to Applied Physics Letters on 3/30/2000 by W.M. Kaminsky et al. discloses a method to degrade and even destroy the ferromagnetism of a GMR multilayer system, such as $Ni_{80}Fe_{20}/Cu/Ni_{80}Fe_{20}/Ni_{80}Cr_{20}$, by exposing this GMR multilayer system to homogeneous 30keV Ga^+ implantation. Ga^+ implantation destroys all appearances of

ferromagnetism at room temperature. The degradation of ferromagnetism occurs primarily because of ion implantation. Kaminsky et al. describe FIB irradiation of a single layer film to fashion a laterally patterned multilayer system. Such an approach would work for patterning the film from the ABS level to produce a read-back sensor. However, this is impractical for mass production of magnetic sensors for the reasons discussed above. Additionally, the lateral scattering of the implanted ions in the material is too great to produce implanted regions sufficiently narrow, and with sufficiently perfect interfaces, to allow a magnetoresistive sensor to be produced which would produce signals competitive with those from thin film sensors.

U.S. Pat. No. 5,079,662 issued on Jan. 7, 1992 to Kawakami et al. discloses a compound magnetic head in which the read element is sandwiched between the poles of the write gap. This patent has mentioned the ion implantation into selected areas of recording heads. However, the ion implantation is performed to increase the coercive field in those areas.

There is a need, therefore, for a MR recording head having improved definition of patterned magnetic sensors and a method of fabricating same.

OBJECTS AND ADVANTAGES

Accordingly, it is a primary object of the present invention to provide a MR sensor with improved shape definition.

It is a further object of the invention to provide a MR sensor with controlled track width.

It is a further object of the invention to provide a MR sensor with well-controlled biasing for magnetic stabilization.

It is an additional object of the invention to provide a method for fabricating such a MR sensor.

5   SUMMARY

These objects and advantages are attained by MR sensors with small track widths defined using ion irradiation and/or implantation at the wafer level.

10   According to a first embodiment of the present invention, a MR structure has a sensor defined by ion irradiation and/or implantation through a mask introduced between the film and the ion source at the wafer level. The unmasked portions of the MR structure are irradiated or implanted with ions, which

15   reduces the magnetoresistance of the unmasked portions. However, materials of the unmasked ion-treated portions are still electrically conductive, which may be used as the lead, or part of the lead structure. Irradiation, as used herein, is distinguished from implantation in that ions irradiating a

20   layer of material have sufficient energy to pass through the layer without being embedded in the layer. Furthermore, the irradiating ions have sufficient energy that they pass through the layer without significant sputtering or milling of the layer.

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The mask may be a photolithographic resist mask located in contact with the surface of the magnetoresistive (MR) structure to cover selected portions of the MR structure and it is sufficiently thick to stop the ions incident on those

30   regions, preventing them from reaching the MR structure. The unmasked portions are exposed to ion beams for patterning the sensor and reducing the magnetoresistance of the unmasked portions while leaving the masked portions, which define the track widths, magnetoresistive. Alternatively, an electron

beam resist mask may be used. A designed TW may be achieved depending on the size of the resist mask used in irradiation and/or implantation process. Fabrication of a MR sensor using a resist mask allows for track width as small as 5nm.

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As an alternative to a resist mask, a stencil mask may be suspended above the surface of a MR structure during ion irradiation and/or implantation. The stencil mask may be produced using photolithography, electron-beam lithography, or

10   other appropriate techniques. By choosing suitable ions and energies to minimize sputtering, the stencil mask may be used repeatedly, thus the cost of producing the mask is of small importance to manufacturing.

15   Alternatively, the sensor of a MR structure may be defined by ion irradiation and/or implantation using a projection ion beam system. In the projection ion beam system, a collimated ion beam is projected through a mask, which is disposed between the MR structure and an ion source. The ion beam is

20   focused by beam optics after passing through the mask. A design TW may be achieved depending on the distance between the mask and the surface of the MR structure, the properties of the beam optics, and the size of features in the mask.

25   According to a second embodiment of the present invention, the magnetization of defined sensors of the types as described in the first embodiment may be stabilized by using a hard bias layer adjacent to the sensor. Alternatively, the magnetization of the defined sensor may be stabilized by using

30   an anti-parallel (AP) pinning layer or an in-stack anti-ferromagnetic (AF) layer.

The methods of using ion implantation/irradiation for reducing the magnetoresistance and magnetic moment of the unmasked

portions described in the first embodiment may be used for AMR, GMR and MTJ sensors. The magnetoresistance of a typical NiMn-based multilayer MR structure falls to around 3% of the as-grown value with an ion dose of 10^{16} ions/cm^2. However,

5 although the ion irradiation reduces the magnetoresistance of the unmasked portions, the magnetic moment of those portions is not substantially altered. Ion implantation with suitable species reduces the magnetic moment and the magnetoresistance of the unmasked portions to zero. The magnetoresistance of

10 typical spin valve samples drops rapidly from around 10% to near zero with increasing dose of implanted ions. The total moment of the films drops to zero after about four monolayers equivalent coverage of ions (about 2×10^{16} ions/cm^2).

15 MR heads having defined sensors of the types as described in the first and second embodiments may be incorporated into a disk drive according to a third embodiment of the present invention. The disk drive includes a magnetic recording medium, a MR head with a defined sensor, an actuator connected

20 to the MR head for moving the MR head across the magnetic recording disk, and a mechanism for moving the disk relative to the MR head.

MR sensors and disk drives made according to the various

25 embodiments of the present invention exhibit edge definitions with narrow track widths suitable for future high density magnetic recording products.

BRIEF DESCRIPTION OF THE FIGURES

30 Fig. 1 depicts a schematic diagram of a MR structure according to the prior art;

Fig. 2 depicts a schematic diagram of a fabrication of a MR structure according to a first embodiment of the present invention;

Fig. **3A** depicts a schematic diagram of fabrication of a MR structure in which an ion beam mill step is used in addition to an ion irradiation/implantation step according to an alternative embodiment of the present invention;

Fig. **3B** depicts a schematic diagram of fabrication of a MR structure in which one mask is used in conjunction with an ion mill step to grossly define the sensing element and a second, smaller mask is used to define the TW via ion irradiation/implantation according to an alternative embodiment of the present invention;

Figs. **3C** depicts a schematic diagram of fabrication of MR sensors using an ion beam projection system according to an alternative embodiment of the present invention;

Fig. **4A** depicts a plot showing the effect of irradiation with 700keV N^+ ions on the normalized magnetoresistance ($\Delta R/R$) of a NiMn-based multilayer;

Fig. **4B** depicts a plot showing the effect of implantation on the normalized magnetic moment of a multilayer MR structure;

Figs. **5A-5E** depict schematic diagrams of sensor stabilization according to a second embodiment of the present invention; and

Fig. **6** depicts a schematic diagram of a disk drive according to a third embodiment of the invention.

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following preferred embodiment of the invention is set forth without any loss of

generality to, and without imposing limitations upon, the claimed invention.

Fig. 2 depicts a cross-sectional schematic diagram of
5   fabrication of a MR structure **200** according to a first embodiment of the present invention. MR structure **200** includes a thin film of magnetoresistive (MR) material, which includes portions **206** and **208**, disposed on a substrate **204** which may include an insulating gap layer and/or a magnetic
10 shield layer. A mask **210** covers the portion **206**, which is a defined sensor of MR structure **200**. The unmasked portions **208** are exposed to the ions **212**. The ions irradiate and/or implant into the unmasked portions **208** and reduce the magnetoresistance of these portions while leaving the masked
15 portion **206** substantially unaltered. However, the unmasked portions **208** are still electrically conducting, which may be used as the lead, or as part of the lead structure. This technique is preferred for implantation since the ion-treated material may be non-magnetic, which may minimize side-reading
20 effects.

The mask may be made of a resist deposited on the surface of a MR structure as shown in Fig. 3A. The resist may be patterned using optical or electron-beam lithography. Alternatively, a
25 stencil mask may be used. Stencil masks can be made from Si or any other suitable material, by any convenient technique, such as optical lithography, electron beam lithography, focused ion beam lithography, or projection ion beam lithography. With a suitable mask it would also be possible
30 to make the sensor shown in Fig. 2 using projection ion beam lithography, wherein the ion beam is focused after passing through the mask. This approach offers the advantage that the patterns in the mask can be considerably larger than the patterns projected on to the MR film which define the sensor

structure.   Fig. 3A illustrates a cross-sectional schematic
diagram of fabrication of a MR sensor **300** with a mask **311** for
patterning and irradiation/implantation with ions according to
an alternative embodiment of the present invention.   MR sensor

5   **300** includes a MR structure containing a defined sensing
element **301** and tails **303**, which are disposed on a substrate
304.   The mask **311** covers a selected portion of the MR
structure to define the sensing element **301**.   The combined
structure of the defined sensing element **301** and tails **303** has

10   been produced by ion milling in conjunction with the mask **311**.
The unmasked portions of the MR structure, e.g., the tails
303, are exposed to the ions **312**.   The ions **312** irradiate
and/or implant into the unmasked portions **303** and reduce the
magnetoresistance of these portions while leaving the masked

15   portion **301** substantially unaltered.   The irradiation and/or
implantation does not affect the magnetization of the masked
portion **301**, thus the sensor is defined.   A design TW of the
sensing element **301** may be achieved depending on the size of
the mask **311**.

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Fig. 3B illustrates an alternative process for defining a
sensor in which the sensing structure is grossly defined in a
first step using a mask which is subsequently removed.   In a
second step, illustrated here, a smaller mask is used in

25   conjunction with ion irradiation/implantation to destroy the
MR in the tails of the sensing structure, thus defining the TW
dimension.   As shown in Fig. 3B, MR sensor **302** includes
sensing element **306** and tails **308**, disposed on substrate **305**,
which are produced from a continuous thin MR film using a

30   conventional ion beam milling process in conjunction with a
first mask (not shown here).   Alternative milling or etching
processes could be used at this step.   A second mask **310** is
inserted between the MR sensor **302** and a source of ions **312**.
Unmasked portions such as the tails **308** are exposed to the

ions **312**. The ions irradiate or implant into the unmasked
portions thereby reducing the magnetoresistance of the
unmasked portions. The reduced magnetoresistance, e.g., in
the tails **308**, defines the TW edge of the sensing element **306**.

5   A designed TW of sensing element **306** is achieved depending on
the size of the mask **310**.

Alternatively, a sensor with tails resulting from a
conventional ion milling process of a MR sensor may be further

10   defined with a projection ion beam system, as shown in Fig.
3C. In Fig. 3C, a MR sensor **332** includes a MR structure
containing a defined sensing element **315** and tails **317**, which
are disposed on a substrate **304**. A rigid mask **314** made from
Si or any other suitable materials is suspended between the MR

15   structure and a source of a collimated beam of ions **312**.
Portions of the mask **314** block the ions from striking one or
more selected portions **315** of the MR structure. Ion optics
316 focus the ions **312** onto unmasked portions **317** of the
sensor **332**. The beam of ions **312** projects onto the unmasked

20   portions **317**. Ion irradiation and/or implantation of the
unmasked portions **317** reduces the magnetoresistance of the
unmasked portions **317** and, thus, defines the sensing element
315. A designed TW of the sensing element **315** may be achieved
depending on a distance between the mask **314** and the surface

25   of the MR sensor **332**, the properties of the ion optics, e.g.,
focal length, and the size of features in the mask **314**.

The technique of using ion irradiation and/or implantation to
define the TW as described in Figs. 2 and 3A-3C may be used

30   for fabricating GMR sensors, such as spin valves, MTJ sensors,
or any magnetic multi-layer sensor structure. These processes
use a broad collimated ion beam and masks to perform TW
definition and allow TW definition of all the sensor elements
on a wafer simultaneously, maximizing the manufacturing

throughput and minimizing cost. Since the ion beam may be applied to a continuous film at the wafer level, the electrostatic discharge (ESD) problem is circumvented. In addition, the ions impinge on the sensor in the direction normal to the magnetic layers of the unmasked portions, and need only penetrate a short distance to do the requisite damage to those layers. Therefore, the ion energy required is low, minimizing milling during irradiation/implantation, thus maintaining a planar geometry suitable for following process steps in the manufacturing flow.

Fabrication using stencil masks may be preferred over fabrication using photoresist masks since the photoresist mask must be cleaned off the surface after patterning, adding a process step, while the use of a stencil mask adds no cleaning step. Projection ion beam patterning offers the same advantage.

In the case of irradiation, the passage of the ions through the sensor can be highly constrained spatially by choice of suitable ions and energies. As a result, the edges of the sensor can be defined to greater precision than is possible using currently available ion milling techniques, irrespective of the nature of the mask used. In order to maximize the sharpness of the pattern made by the ions, the ion species and energy must be selected such that the lateral scattering of ions beneath the mask edge is minimal while the required ion dose is achieved. Usually, this is accomplished by selecting low-Z ions, such as He^+, having a small projected range in the magnetic layer. In previous studies, the parameters of ion beams for which the magnetic response is suitably modified, such as He^+ at 30keV, are consistent with low lateral spreading. The small amount of lateral scattering of the ions in the sensor film, together with the lack of physical

etching, results in a sensor with essentially vertical edges rather than with the tails found in the current products. This significantly improves the performance of the MR heads that incorporate these sensors.

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The processes of fabricating MR sensors depicted in Figs. 2 and 3A-3C provide several other advantages. The coercivity of the hard bias layer may be increased by ion exposure since ion irradiation and/or implantation of magnetically soft thin films can cause the thin films to become magnetically harder. Thus in addition to defining TW of the sensor, the ion irradiation and/or implantation processes can be optimized to induce a suitable coercivity in the film to each side of the sensor, providing a hard bias layer which abuts the sensor in an ideal manner.

The effect of the ion irradiation on the magnetoresistance of the unmasked portions of MR sensors is described in Fig. 4. Specifically, Fig. 4A depicts a plot of the normalized magnetoresitance ($\Delta R/R$) of the unmasked portions of a NiMn-based multilayer MR structure with a flux of N^+ ions at 700 keV and at a range of dose up to 10^{16} ions/cm^2. Over this range, the magnetoresistance $\Delta R/R$ is observed to fall to around 3% of the magnetoresistance of the as-produced structure. This effect also occurs with other spin valve and magnetic tunnel valve structures including NiO.

Alternatively, controlled doping of the MR sensor with Cr, V, Al, Mo or similar elements also serves to greatly reduce the MR signal from the implanted area and thus may also be used to define the TW.

The ion irradiation reduces magnetoresistance $\Delta R/R$ of the unmasked portions of MR sensors, without substantially

reducing the magnetic moment. The magnetic moment, and thus
the magnetoresistance $\Delta R/R$, of the unmasked portions may be
reduced to zero by ion implantation, thus minimizing the side-
reading effect of the unmasked material adjoining the sensor
since it is no longer magnetic. An example is given below to
show the effect of the ion implantation on the magnetic moment
and the magnetoresistance $\Delta R/R$ of spin valves. An exemplary
spin valve with a complete structure denoted by
$Si/Ru(20Å)/NiFe(20Å)/IrMn(80Å)/CoFe(13Å)/NOL/CoFe(25Å)/Cu(25Å)$
$/Co_{90}Fe_{10}(5Å)/Ni_{80}Fe_{20}(40Å)/Ru(50Å)$ includes a substrate of Si,
two seed layers of Ru 20Å thick and NiFe 20Å thick, an
antiferromagnetic layer of IrMn 80Å thick, a pinned layer
containing a first layer of CoFe 13Å thick, a nano-oxide layer
NOL, and a second layer of CoFe 25Å, a spacer layer of Cu 25Å
thick, a free layer containing a layer of $Co_{90}Fe_{10}$ 25Å thick and
a layer of $Ni_{80}Fe_{20}$ 40Å thick, and a overcoat layer of Ru 50Å
thick. This sample was irradiated with Cr^+ ions at dose
between $2x10^{14}$ and $2x10^{16}$ ions/cm^2. The Cr^+ ion energy, 20 keV,
was chosen so as to stop most of the ions in or near the free
layer, as determined from a simulation of the implantation
process. The Ru overcoat layer may be diminished somewhat by
milling at the high Cr^+ doses, but this effect may be minimized
by using a low-Z element as the overcoat material. The pre-
implantation magnetoresistance $\Delta R/R$ value of the sample was
about 10%. The $\Delta R/R$ value dropped rapidly with increasing
dose, and reduced essentially to zero after about a monolayer
coverage of ions (about $3x10^{15}$ ions/cm^2). As shown in Fig. 4B,
which depicts a plot of normalized magnetic moment of the
unmasked portions of a MR multilayer structure as a function
of Cr^+ ion dose, the total moment of the films dropped to zero
after about 4 monolayers of ions (about $2x10^{16}$ ions/cm^2). The
loss of magnetic moment likely occurs because doping with Cr^+
drives the Curie temperature below room temperature,
transforming layers in the film from ferromagnetic to

paramagnetic at room temperature. The Cr^+ ions caused a massive intermixing of the atoms in the multilayers, as well as the loss of some overcoat Ru to sputtering.

5   The sensor magnetoresistance $\Delta R/R$ can also be increased in the process of patterning TW by ion irradiation, since for some magnetoresistive multilayer (ML) systems a small ion dose causes an increase in the magnetoresistance (MR). (e.g. D. M. Kelly et al., Increases in giant magnetoresistance by ion
10 irradiation in Physics Review B 50 3481 (1994)). Thus, by applying a low radiation dose to the entire film to increase the MR signal of the ML, and then inserting the mask over the element and continuing with the irradiation until the MR of the material surrounding the element is diminished to zero, a
15 sensor with enhanced MR is shaped.

The ion beam parameters will typically be selected to optimize the change of magnetic properties of the bombarded sensor layers. Preferably, the chosen ion beam parameters also
20 facilitate such ideals as low ion dose (short processing time), low sputtering damage to the mask, economical ion beam generation (low energy, typically < 100 keV), large beam area and freedom from debris. The effect of the ions on the magnetic properties may, in some multilayer sensors, depend
25 only on the energy loss processes as the ion passes through the ML, or different changes may be achieved by implantation to alter the phase structure or chemistry of the sensor layers themselves. The ion species and energy will determine whether the ion stops within the sensor (implantation) or outside
30 (irradiation). The important mode of ion-solid interaction may be the ionization energy deposited at the MR interfaces by the passing ion, or alternatively it might be the rate of collisional energy transfer. Furthermore, the requisite amount and form of energy transfer may be equally well

provided by almost any ion species, given enough energy to pass through the ML. Typically, the ion energy chosen could be in the range from about 10keV to about 1MeV. If the ion is implanted to alter the ML composition, the ion species are

5   predetermined, so the energy will be chosen to lodge the ions within the ML, which may be in the range from about 10keV to about 1MeV. All the ion energy deposition and stopping characteristics may be predicted by the Monte Carlo simulation software TRIM (J.P. Biersack and L. Haggmark, Nuclear

10   Instrument and Methods in Physics Research 174 257 (1980)). A person with average skill in the art will be familiar with the choice of ion species and ions energies for the irradiation or implantation in a target material typical of MR sensors using Monte Carlo software.

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According to a second embodiment of the present invention, the magnetization of a MR sensor may be stabilized by using longitudinal bias for improvement of the sensor performance. Fig. 5A shows a schematic diagram of a MR sensor **500**. MR

20   sensor **500** includes a sensing element **505** with tails **507**, shaped from a continuous film using ion beam milling process in conjunction with the mask **509**, located on a substrate **504**. The shape of the sensing element **505** and the TW are defined with an ion implantation/irradiation process using mask **509**.

25   The magnetization of sensing element **505** is conventionally stabilized by hard bias layers **512** adjacent to both sides of the sensor **505**. Two leads **514** are disposed over the hard bias layers **512** for transmitting electrical signals. However, the hard bias layers **512** may become very thin near the top surface

30   of the sensing element **505** and/or may not closely abut the sensing element **505**, leading to poor sensor performance.

Fig. 5B illustrates a schematic diagram of a MR sensor **501** including a sensing element **506** with the tails **508** located on

a substrate **504**. The TW of the sensing element **506** is defined by introducing an extra mask **5 1 0** for ion implantation/irradiation process. This mask is smaller than the mask used for the milling step of patterning the combined

5   structure of sensing element **506** and tails **508**. Two leads **515** overlay on the hard bias layers **513** adjacent the sensor **506**, which transmit the electrical signals. Hard bias layers **513**, which are magnetically coupled to the tails **508**, abut and bias the sensing element **506**.

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Alternatively, the magnetization of the sensor of a MR sensor may be stabilized by using an anti-parallel (AP) pinning layer as shown in Fig. 5C. Fig. 5C depicts a schematic diagram of a MR sensor **503** including a sensing element **519** with tails **516**

15   located on a substrate **504**. An AP pinning layer including portions **517** and **521** is deposited on the sensor layer. Portion **521** is implanted with ions of species and energy such that the magnetic coupling between portion **521** and underlying portion **519** is destroyed, thus freeing portion **519** to behave

20   as a sensing element. The TW of the sensing element **519** is defined by introducing extra masks **511** on the portions **517** of the AP pinning layer for protecting these portions **517** from the ion implantation process separately from the milling step of patterning the MR structure. These portions **517** of the AP

25   pinning layer couple with the free layer of the sensor layer in portions **516**, thus these portions **516** are no longer acting like a sensor. Portions **516** and portions **517** stabilize the ends of the sensing element **519**, which improves the sensing element **519** performance. The masks **511** also cover leads **518**

30   disposed adjacent the portions **516** of the sensor layer and the portions **517** of the AP pinning layer.

Furthermore, the magnetization of a MR sensor may be stabilized by using an in-stack antiferromagnetic (AF) layer

as shown in Figs. 5D-E. Fig. 5D depicts a schematic diagram
of a MR sensor **520** including a sensing element **539** with tails
521 located on a substrate **504**. Two leads **527** may be disposed
adjacent to the tail **521** for transmitting electrical signals.
5   An in-stack AF layer **529** is disposed on the sensing element
539. The TW of the sensing element **539** may be defined by
introducing a mask **522** on the AF layer **529** for an ion
implantation/irradiation process following a milling step of
patterning the MR structure. The AF layer **529** stabilizes the
10   magnetization of the sensing element **539**.

Fig. 5E illustrates an alternative schematic diagram of a MR
sensor **540** having the magnetization of the sensor stabilized
by using an in-stack AF layer. MR sensor **540** includes a
15   sensing element **523** having tails **524** located on a substrate
504. An AF layer having a first portion **531** covers the
sensing element **523** and a second portion **530** disposed on the
tails **524**. The TW of the sensing element **523** may be defined
by introducing an extra mask **528** for an ion
20   implantation/irradiation process separate from a milling step
of patterning the MR structure. Two leads **526** are disposed
adjacent the tails **524** and the portion **530** of the AF layer for
transmitting electrical signals. The portion **531** of the AF
layer stabilizes the magnetization of the sensing element **523**.
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MR heads incorporating MR sensors of the types depicted in
Figs. 2, 3A-3C, and 5A-5E may be incorporated into disk
drives. Fig. 6 depicts a schematic diagram of a disk drive
600 according to a third embodiment of the present invention.
30   The disk drive **600** includes a magnetic recording disk **602**, a
MR head **604** with MR sensor **601** having features in common with
the MR sensors described above with respect to Figs. 2, 3A-3C,
and 5A-5E, an actuator **606** connected to the MR head **604**, and a
mechanism **608** connected to the disk **602**. The mechanism **608**

moves the disk **602** with respect to MR head **604**. The actuator **606** moves the MR head **604** across the magnetic recording disk **602** so the MR head **604** may access different regions of magnetically recorded data on the magnetic recording disk **602**.

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It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and

10   their legal equivalents.